Official Journal of the World Water Council
Water Policy

Water Policy Vol 25 No 8, 780 doi: 10.2166/wp.2023.261

When the law is unclear: challenges and opportunities for data and information exchange in the Tigris-Euphrates and Indus river basins

Qaraman M. Hasan [a,b,*], Sarkawt Ghazi Salar [c], Durgeshree Raman[d], Sam Campbell[d] and Ibrahim Qasim Palani[c]

[a] School of Advanced International Studies, Johns Hopkins University, Washington, DC, USA
[b] Department of Law, College of Human Sciences, University of Raparin, Kurdistan Region, Iraq
[c] Department of Geography, College of Education, University of Garmian, Kurdistan Region, Iraq
[d] Te Piringa – Faculty of Law, University of Waikato, Hamilton, New Zealand
*Corresponding author. E-mail: qhasan1@jhu.edu

QMH, 0000-0003-3815-3734; SGS, 0000-0002-9718-404X

ABSTRACT

Data and information exchange are vital for long-term transboundary water cooperation. However, many transboundary river basins lack regular data exchange between riparian States. In many cases, this is simply a feature of the generally fragmented nature of transboundary water cooperation; in others, transboundary river basin data sharing may be withheld for geopolitical reasons. The Tigris-Euphrates and Indus river basins are among the most highly politicized river basins globally. Cooperation between riparians is complicated by a lack of certainty regarding data, information exchange and legal obligations, as upper riparians in both basins have persistently objected to the customary law of international watercourses. With reference to international water law, this article ascertains the level of data and information exchange in these two basins, both through formal and informal structures, as well as prevalent obstacles and the institutional and technological responses to them. Despite significant challenges, the authors argue that technological advances can stimulate enhanced riparian cooperation.

Key words: Climate change, Data and information exchange, Indus, International law, Tigris and Euphrates, Transboundary rivers

HIGHLIGHTS

- The existing legal frameworks in these basins provide a platform for data and information exchange to take place.
- The greater cooperation and participation through quality data and information exchange between and within riparian states would mean that IWRM could be meaningfully implemented.
- Implementing international law principles depend on the level of cooperation among watercourse states.
- Sharing data with local people in the basins contributes to better regional and international cooperation.

1. INTRODUCTION

In the Tigris-Euphrates and Indus river basins, downstream riparian states are largely dependent on upstream states for addressing factors which make them particularly vulnerable to changes in downstream ecological flows, both in terms of water quantity and quality, whether due to upstream projects or environmental factors, or both. As the transboundary water-related issues in these two basins are severe, data and information exchange

would be the first and fundamental step towards cooperation and sustainable management of the two basins. However, there is no comprehensive governance framework promoting data and information exchange in either basin. There have been attempts to establish some governance measures, but none that address the broad range of issues across the basins. One significant obstacle to the formation of such mechanisms is that upper riparians in both basins have persistently objected to the customary law of international watercourses, and, by extension, the data and information sharing obligations which apply to many transboundary river basins around the world. This has created an environment of uncertainty which has stymied cooperation. Despite these obstacles, this article proposes that technological advances can assist in improving cooperation, even in these two complex cases.

Turkey, Syria and Iraq share the Tigris-Euphrates, but the riparians have no agreement to cooperate and share data. After decades of negotiation, Turkey and Iraq established the Joint Technical Committee (JTC) in 1980, and Syria joined the Committee in 1983. The JTC held 16 meetings until 1993. In these meetings, the members of the JTC exchanged significant data on hydrological and meteorological conditions as well as ongoing and future projects in the basin. In 1993, the JTC failed to achieve its objectives and the meetings were suspended (Kibaroglu, 2019). Since that time, these states have failed to find a solution for sharing the two rivers' water and data. After constructing several dams in Turkey as a part of the GAP project (discussed below), the riparian states returned to negotiation for utilizing water and exchanging data in 2009. Several memoranda of understanding have been signed among them in 2009, 2014 and 2019, but exchanging data is still very weak and excludes Syria.

The Indus, which is shared by Tibetan China, India, Pakistan and Afghanistan, is slightly better positioned in comparison to the Tigris-Euphrates, but only India and Pakistan have a water sharing agreement – the Indus Waters Treaty 1960. This Treaty provides for a monthly exchange of data (Article VI(1)). The Permanent Indus Commission (PIC) established under the Treaty is entrusted to maintain cooperative arrangements for the implementation of the Treaty provisions (Article VIII(4)), which includes the obligation to exchange data regarding the flow of, and utilization of the Indus waters. This includes daily discharge data relating to the flow of the tributary rivers at all observation sites and daily withdrawals at the heads of all canals (Article VI(1)(a) and (c)). Parties are also entitled to request the supply of any additional data relating to the hydrology of the Indus (Article VI(2)). This paves the way for both parties to access and analyse data and information and implement any measure(s) which enable them to manage their part of the basin better, but this does not address basin-wide issues as Afghanistan and China do not actively participate in data exchange and information sharing by virtue of them not being signatories to the Indus Waters Treaty.

This article is an attempt to present the obstacles and challenges to data and information exchange in these vital basins. It also highlights the opportunities for taking data and information exchange as the fundamental step towards long-term and sustainable management of the two basins with technology as a focal point. In doing so, the paper is structured as follows: after introducing the two basins and their transboundary issues in the first section, the paper outlines the applicable provisions of international law in Section 2. Section 3 presents the significant role of technologies in facilitating data and information exchange among riparian States. Section 4 broadly assesses data and information exchange challenges to link them with contemporary environmental challenges, followed by Section 5, which presents solutions and opportunities for the challenges that are highlighted in Section 4.

1.1. Tigris and Euphrates river basin

Tigris and Euphrates are among two of the most significant rivers in the Middle East. They originate in Southeast Turkey. The Euphrates enters Syria, then Iraq from the west of the country. The Tigris makes the Iraqi and Syrian border, joining the Euphrates before discharging into the Persian Gulf (Figure 1). Tigris is 1,800 km^2 long, and its basin area is 221,000 km^2. Tigris's basin area is shared by Iraq 56.1%, Turkey 24.5%, Iran 19% and Syria 0.4% (UN-ESCWA, 2013). The Euphrates is longer than Tigris and is 2,786 km long with a 440,000 km^2 basin area.

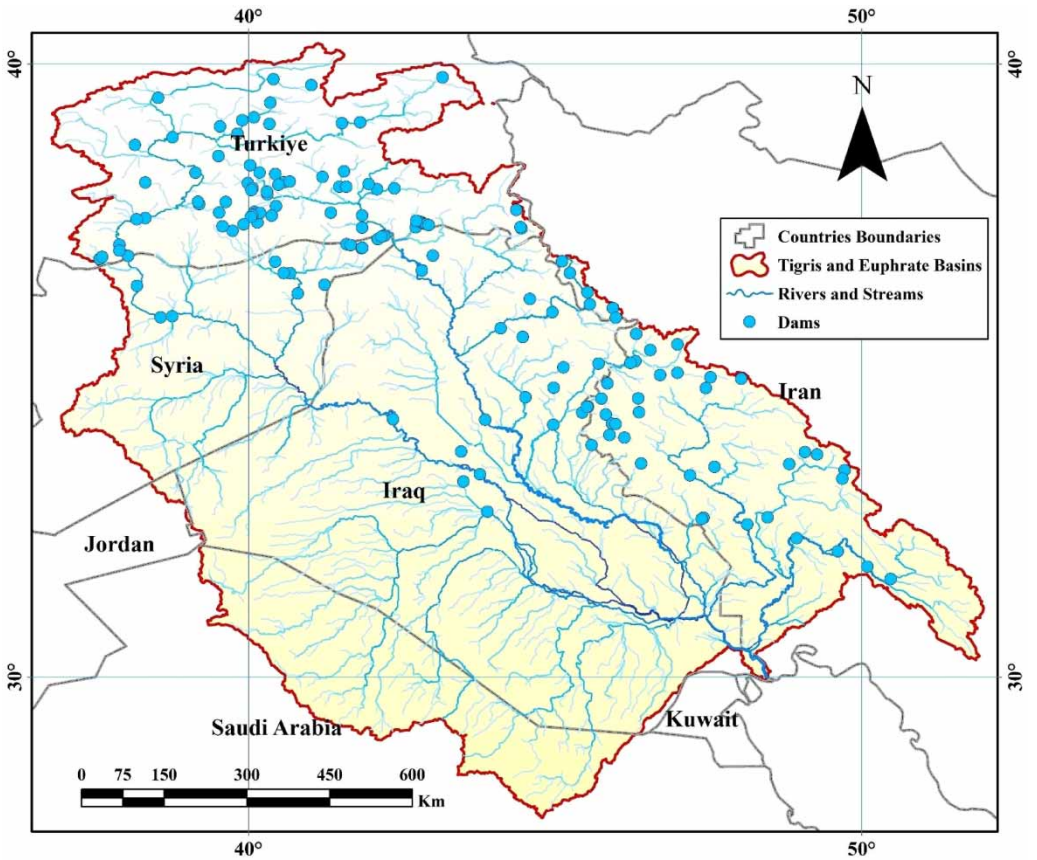

Fig. 1 | Tigris-Euphrates river basin and the dams in the basin. The map shows how upstream countries built dams on the two rivers, negatively impacting downstream countries Iraq and Syria.

Its basin area is shared by Iraq 47%, Turkey 28%, Syria 22%, Saudi Arabia 2.97% and Jordan 0.03% (UN-ESCWA, 2013). The two rivers flowed naturally for thousands of years until Turkey constructed several dams and tunnels on the two rivers. The idea of developing water resources in Turkey dates back to the 1950s. In the 1960s and 1970s, the Turkish government started discussing the possibility of irrigating large areas of Southeast Turkey (Kibaroglu *et al.*, 2005).

However, the South-Eastern Anatolia Project, known as 'GAP' in Turkey, was officially announced after the Euphrates Basin Development Report, Lower Euphrates Development Report and Tigris Basin studies were completed in 1977. With growing ambitions, the GAP Regional Development Administration (GAP-RDA) was created in Turkey, and it started work on the GAP in 1989 (GAP-RDA, 2021). The GAP consists of 22 major dams, 19 hydropower generations and several tunnels on the Tigris, Euphrates and their tributaries (Yuksel, 2015). Most of the planned dams have been completed, and they have negatively affected water quality and quantity in Syria and Iraq (Hasan *et al.*, 2019). Previously it was estimated that the total flow of the Tigris would be decreased by 33% and the Euphrates by 50% (Kliot, 1996). The study found that the main reason for this decrease is the construction of water resource projects on the river, but climate change is also a contributing factor. The later sections prove that the flow of the two rivers considerably decreased in the downstream counties.

Turkey's water projects raised concerns in both Iraq and Syria in the late 1970s. Hence, Iraq proposed to establish the JTC, but it failed to find a mechanism for negotiating water allocation in the basin (Bagis, 1997). The member states of the JTC disagreed on several fundamental issues. Firstly, Turkey refused shared sovereignty over the two rivers, which the two downstream countries required. Secondly, Iraq and Syria concentrated on the Euphrates river separately, but Turkey attempted to discuss the two rivers as one single basin (Kibaroğlu, 2002). Finally, according to Turkey, the two rivers create one basin because they join in Shatt al-Arab. Iraq and Syria have rejected this idea because they are separate rivers and basins (Kibaroglu & Ünver, 2000).

Turkey continued to complete GAP in the last three decades without sharing data or consulting the downstream riparians (Salewicz *et al.*, 2021). However, the countries have a legal responsibility to allocate water equitably, share data with other riparian countries and consult with each other. According to Article 6 of the Protocol on Matters Pertaining to Economic Cooperation, Turkey promised to release 500 m^3/s as a minimum flow to Syria (Turkey, 1987). Syria also guaranteed to release 58% of the Euphrates river to Iraq according to an agreement between Iraq and Syria in 1991 (Syria, 1990). These agreements obligate the three countries to share the basin's water in an equitable and reasonable manner. However, they cannot be implemented without reliable and transparent data exchange among these riparians.

1.2. Indus river basin

The Indus river basin is located in South Asia. It originates in Tibetan China and borders India, Pakistan and Afghanistan (Figure 2). The total length of the Indus basin is about 2,900 km, rising from the top of the Himalayas and discharging into the Arabian Sea. Its total area is 1.1 million km^2 which Pakistan shares (47%), India (39%), Tibetan China (8%) and Afghanistan (6%). The basin has many tributaries, including three eastern rivers; the Ravi, Beas and Sutlej, the unrestricted use of which is allocated to India, and the three western rivers; the Indus, Jhelum and Chenab, the unrestricted use of which is allocated to Pakistan, under the Indus Waters Treaty; Articles I(5),(6), II(1) and III(1).

Currently, the basin's health is threatened by over-extraction, pollution, damming and infrastructural development as well as climate change (Raman, 2015). All of these are impacting not just the quantity of the Indus waters but the quality as well. As discussed below, both India and Pakistan have an inventory of damming and infrastructural development in the basin. Glacial melt in the Himalayas due to climate change is particularly damaging to Pakistan, which is now suffering from frequent episodes of floods and droughts (Khan, 2022). The most recent floods saw one-third of Pakistan under water (Mallapaty, 2022). If disasters of this scale were to recur, pre-emptive measures to combat them would crucially depend on reliable data and information exchange in the Indus basin as the object of the Treaty is to provide for 'the rights and obligations of each in relation to the other concerning the use of these waters' (Preamble). Hence, it is purely a water allocation agreement, which only deals with matters ancillary to it, and to the exclusion of the other riparian states.

2. INTERNATIONAL LAW AND DATA SHARING

One defining feature of transboundary cooperation for both the Tigris-Euphrates and Indus river basins is uncertainty surrounding the application of the law of international watercourses to upper riparian States; namely, Turkey and China. There are a range of procedural obligations under International Water Law that require watercourse states to exchange certain information about shared international watercourses and their utilization. These obligations are outlined in the Convention on Non-Navigational Uses of International Watercourses ('UN Convention') (Convention on the Law of the Non-navigational Uses of International Watercourses, 1997) which entered into force in 2014. The UN Convention has relatively few parties, but, due to its extensive negotiation, it is a highly persuasive instrument for determining customary obligations concerning transboundary rivers

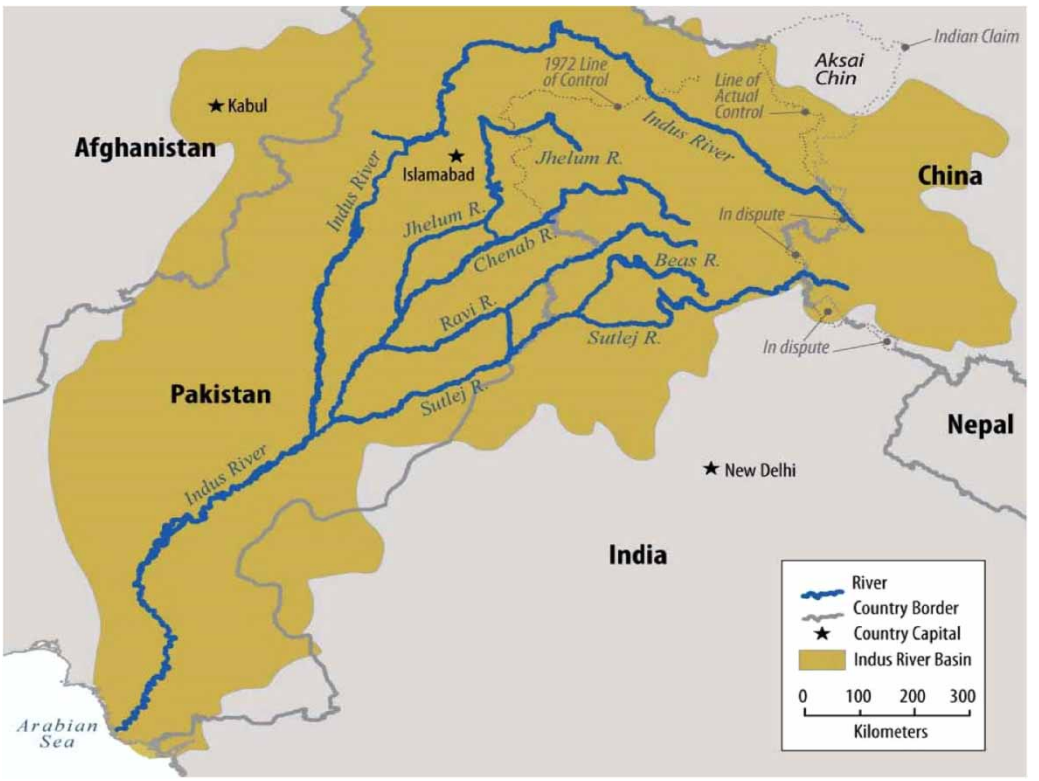

Fig. 2 | Indus river basin. The map shows the river basin and its importance for basin states.

(McIntyre, 2007). The Convention has been considered to be a codification (McCaffrey, 2001) and an authoritative statement (McCaffrey, 2008; Rieu-Clarke, 2013) of customary law in the area. As such, the principles codified in the Convention apply to all states, with the possible limited exception of states who persistently object to them (see Fisheries Case, *United Kingdom v Norway* [1951] ICJ 116 at 131; Sands *et al*., 2012). The status of the customary principles reflected in the Convention in relation to Turkey and China is somewhat unclear, as both objected to the Convention upon its formation, therefore potentially becoming 'persistent objectors' who can avoid the customary norms codified therein. The persistent objector principle is controversial, and many authors have argued that it no longer applies (see Cassese, 2005; Petersen, 2017). Nonetheless, Turkey considers itself to not be bound by the customary law of international watercourses, and there is at least an argument, based on the Fisheries Case, that it is correct in that assertion. China's legal position is more nuanced as outlined below.

Turkey and China were two of only three states to vote against the adoption of the UN Convention in the United Nations General Assembly, objecting to the Convention's failure to affirm territorial sovereignty over waters within a state's territory (United Nations, 1997, p. 8). The Turkish delegation declared that 'this Convention does not and shall not have any legal effect for Turkey in terms of general and customary international law' (United Nations, 1997, p. 5). China did not unequivocally reject the Convention in the same manner, noting instead that it reserved 'the right to address the question of the non-navigational uses of international watercourses with its neighbours in a fair and reasonable manner and in accordance with relevant international practice and with bilateral watercourse agreements' (United Nations, 1997, p. 7). Indeed, China has concluded

treaties with a number of watercourse states of other river basins which reflect some key customary norms, including equitable utilization; however, it shows no intention of supporting the UN Convention (Chen *et al.*, 2013; Devlaeminck & Huang, 2020). India and Pakistan abstained from voting on the UN Convention. Both objected to certain articles, particularly those which related to dispute resolution, though neither specifically objected to the sharing of data and information (United Nations, 1997, pp. 5, 9). Iraq, Jordan and Syria have all ratified the UN Convention (United Nations, 2022).

The Preamble of the UN Convention takes 'into account the problems affecting many international watercourses resulting from, among other things, increasing demands and pollution' (para 4), expresses 'the conviction that a framework convention will ensure the utilization, development, conservation, management and protection of international watercourses and the promotion and sustainable utilization thereof for present and future generations' (para 5) and affirms 'the importance of international cooperation and good-neighbourliness' (para 6). Within this framework, states are under an obligation to regularly exchange 'data and information on the condition of the watercourse, in particular that of a hydrological, meteorological, hydrogeological and ecological nature and related to the water quality as well as related forecasts' that is 'readily available' (art. 9(1)). Where requested data and information is not readily available, the requested state is under an obligation to 'employ its best efforts to comply with the request' (art. 9(2)) and 'to collect and, where appropriate, to process data and information in a manner which facilitates its utilization by the other [requester] State' (art. 9(3)).

The UN Convention has separate provisions with regards to planned measures, which entails a duty to notify, consult and negotiate. Watercourse states are obliged to provide timely prior notification to co-riparians of planned measures, which may have a significant effect upon their territory (UN Convention, 1997, art. 12). The notification must be accompanied by relevant technical data and any environmental impact assessment (EIA) which has been undertaken (UN Convention, 1997, art. 12). While under the UN Convention, carrying out an EIA is optional, it is noted from the Permanent Court of Arbitration's *Indus Waters Kishenganga Arbitration* referring to the International Court of Justice's *Pulp Mills* case, that the principle of sustainable development translates into an ongoing duty under international law to undertake an EIA where there is a potential risk to the quantity and quality of international basin waters from large-scale planned projects (ICJ, 2010; Raman, 2014, p. 59). States sharing an international watercourse must also share information, consult and negotiate with respect to planned measures and their effects (UN Convention, 1997, arts. 11, 17).

In addition, states need to take all appropriate measures to prevent or mitigate harmful conditions, whether natural or caused by human actions. This can include flooding conditions, erosion, drought and other hazards (UN Convention, 1997, arts. 11, 17). These duties are also recognized in other prominent international water law treaties (Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 1992, arts. 9(2), 11(3)–(4), 13, 14), and assessments of the International Law Association concerning the normative expectations of states (International Law Association, 1967, art. 29; International Law Association, 2004, arts. 32(2)–(3), 33(2)–(3), 34(2),(4), 56, 57–61). The data sharing duties have broader normative implications than mere information exchange if the threats to the basins' water resources are to be addressed effectively. Data exchange between co-riparians is also crucial for achieving equitable utilization (International Law Commission, 1994; McCaffrey, 2019); the cornerstone principle of international water law (McCaffrey, 1986; Salman, 2015). The reliability of discharging this obligation depends on the utility of new technologies.

3. DATA SHARING AND THE IMPORTANCE OF NEW TECHNOLOGIES

Water resources can be managed and monitored with high efficiency and accurate *in situ* information, new sources of information, and modern technology that are developing day after day if the participating basin countries intend to discharge their data sharing obligations. Space technology, digital information and

communication technologies have all aided in the effective representation and modelling of Earth's phenomena (Anbazhagan *et al*., 2011). The exchange of data and information is essential in transboundary water basin management, especially in light of the growing threats to transboundary rivers, as illustrated below. There are two ways to get data and information. The first is that each country shares information within its boundaries with the other countries participating in the transboundary water basin management.

The second is the important and valuable data and information that can be found on the pages and platforms belonging to major scientific institutes worldwide (Prost, 2014; Chang, 2019). The examples of these platforms are NASA Reverb (reverb.echo.nasa.gov), Rapid Response (lance.nasa.gov/imagery/rapid-response/), USGS EarthExplorer (earthexplorer.usgs.gov), USGS GloVis (glovis.usgs.gov), ESA EOLi (eoli.esa.int) and Sentinel Hub EO Browser (https://apps.sentinel-hub.com/eo-browser/). They provide countless data and information about the Earth's surface from decades ago to today, making it easier to monitor the ground and surface water, including transboundary water basins, to overcome the challenges (Salar *et al*., 2018; Liang & Wang, 2019). These data and information have a spatial resolution of kilometres, metres, centimetres and millimetres. They are available for free or for a fee, depending on the spatial and temporal resolution required. For example, most information with a cell size of 10 m or above is free, whereas information with a resolution of less than 10 m is not. The aims of their uses are determined by their spatial and temporal resolution.

The recent challenges facing water managers are to find a sustainable strategy to open the advantages of the water cycle and make them available to a wide range of social and economic sectors (GWP, 2009; Jacobs & Nienaber, 2011; Orme *et al*., 2015). According to Koeppel (2008), growing competition for transboundary water resources among economic sectors, ecosystems, people and governments is often assumed to lead necessarily to conflict. Climate change, economic development and demographic shifts all appear to increase the chances of a negative outcome on water management (Johns & VanNijnatten, 2021). It has been suggested that integrated water resource management (IWRM) is a suitable strategy for all aspects of basins. The IWRM includes the integration between the watershed components such as relief, soil, water yield, wetland and human (GWP, 2009; Ganoulis *et al*., 2013). Any change that occurs to the ground surface in the upstream countries will have repercussions in the downstream countries. Data exchange significantly reduces the risk, but lack of data sharing has negative consequences on downstream counties. For example, reducing the water supply from the upstream countries in 2021 led to a decrease in the water levels and electricity in the downstream countries' dams: the Tabaq Dam in Syria and the Darbandikhan Dam in Iraq. In the Indus basin, damming and development by India upstream has been a constant cause for concern for Pakistan with reduced ecological flows into its side of the basin (Indus Waters Kishenganga Arbitration, Pakistan v India, 2013). With data and information sharing, these repercussions can be predicted and thus avoided. However, these are not without challenges.

4. CHALLENGES FOR SHARING DATA AND INFORMATION IN TRANSBOUNDARY RIVER BASINS

Data and information exchange are facing many challenges. There is inequality and imbalance in the geopolitical power among riparians, so the incentive to avail information becomes lacking. With the advancement in technologies, data are more widely available now, but data regarding many aspects cannot be obtained if states have no will and desire to share it.

4.1. Legal and political challenges

Any agreement between the countries participating in the transboundary basins should be to benefit the basin health and *inter alia*, to the benefit of the peoples of these countries by mitigating any negative effects on the countries (Hensengerth *et al*., 2012). GWP (2009) states that riparian states must work together to develop management systems that will reduce the effects of natural disasters, provide water for various human activities and

keep the environment safe and healthy. In the Tigris-Euphrates, there have been many meetings and agreements among its riparian states, which are not stable and did not continue for long periods to manage water without adhering to the texts agreed upon between these countries with the absence of international organizations, especially the United Nations. Hence, disagreement is the main reason for the lack of a legal framework as an institution in which the committees of the participating countries in the basin work actively (Brachet & Valensuela, 2012).

In addition, a narrow nationalist understanding in both Iran and Turkey for water management is a major challenge for future cooperation and data exchange. The GAP in Turkey and some dams in Iran have had a severe detrimental impact on downstream countries and the Kurdish people inside these two states (Yadirgi, 2020; Hassaniyan & Sohrabi, 2022), the traditional owners of the upper part of the basin or southeast of Turkey, northeast of Syria, north of Iraq and west of Iran (Hasan, 2023). For instance, more than 350,000 people were displaced by the GAP until 2004 (Morvaridi, 2004). EIA was dismissed in constructing all these dams, Kurdish people were not consulted, and great global heritage was lost (Kornfeld, 2020). Thus, a lack of communication and consultation is prevalent inside riparian territories and data has not been shared with people who live within the basin.

Management of the Indus is also defined by the political relations between India and Pakistan. Since India was divided, and Pakistan came into existence as an independent country in 1947, the two countries have fought over Kashmir, which remains an unresolved issue to date. Geopolitical tensions are also present in the water stressed Kabul sub-basin between upstream areas in Afghanistan and downstream areas in Pakistan (Atef *et al*., 2019). Given the level of water stress in the basin (see under environmental challenges), global assessments are that the Indus basin is at considerable risk of future conflicts (Smolenaars *et al*., 2022). This is despite the success of the Indus Waters Treaty which has survived many disputes, arbitration and wars between India and Pakistan. It will be ideal if at least Afghanistan could become a party to the Treaty so that there is active participation between the three key states in the basin's management. This would also be an optimal time to revise the decades-old Treaty to reflect the development of international law and challenges such as climate change.

Finally, disagreement and lack of independent basin institutions is a significant challenge for management and data sharing in these basins. There have been agreements and committees among riparians, but they were not comprehensive enough to cover all the states in the basins. The absence of Afghanistan in the Indus Water Treaty and the absence of Iran in agreements on the Tigris and Euphrates, are a fundamental challenge for a comprehensive assessment of the basins and data exchange. The PIC is much better placed because, despite the political challenges, the Commission has continued to discharge its obligations under the Indus Waters Treaty. However, technological challenges remain.

4.2. Technical challenges

The relevant traditional and modern institutions constitute the main sources of information. The traditional sources are located within the sovereign and political borders of each participating country in each river basin, which can only be obtained through the official channels of these countries. Whereas modern sources of information cross political borders and are widely available. The quantity and quality of these data are restricted by the nature of changes and the projects being implemented. Thus, comprehensive and accurate data, particularly related to water quality inside states, cannot be obtained without cooperation among riparians, as illustrated below.

For example, some dams in GAP in Turkey have clear dimensions and landmarks, information pertaining to which can be easily collected through modern sources, including cross-border remote sensing sources. The Iranian Tropical Project, located between Sanandaj and Elam provinces, extends hundreds of kilometres along the Iranian-Iraqi border. The objective of the project is to transfer all the water over the capacity of the dams

and projects built on the streams and water branches feeding the Sirwan River, which is one of the main tributaries of the Tigris River, into channels and tunnels within the territory of Iran so that the amount of water feeding the Sirwan River is close to zero (Faraj & Zaidan, 2020). Obtaining information about this type of project without referring to the official authorities represents a serious challenge to modern sources of information since the nature of this project is invisible and cannot be physically sensed as a phenomenon by remote sensing devices, except through its consequences and repercussions of decreasing water discharges and environmental degradation.

Under the Indus Waters Treaty, the parties are under an obligation to furnish or exchange data and information through the PIC, whereby the Commissioners act as a regular channel of communication (Article VIII(1)(a)). The Treaty also provides for a monthly exchange of hydrological data collected daily regarding river flows, extractions for and releases from reservoirs, withdrawals, escapades (water flow from water infrastructures such as headworks, barrages or dams) and deliveries (Article VI(1)(a)–(e)). This has been taking place since the Treaty's inception in 1960 (Indus Waters Kishenganga Arbitration, Pakistan v India 2013, para 75). Furthermore, under the Treaty, either party can request any additional data, including hydrological data for the tributory rivers (Article VI(2)). While this does promote the exchange and coordination of hydrological data concerning: (1) aspects of the hydrological regime, that is the quantity and dynamics of water flow, and (2) river continuity (though this too is limited to Pakistan's border's on India's side), it does not make any connection to groundwater bodies and morphological conditions such as structure and substrate of the river bed and structure of the riparian zone. Absent basin-wide data collection means that even the rate of glacial melt feeding Pakistan's side of the Indus river is unclear (Mallapaty, 2022) which is crucial to understanding and monitoring ecological flows in the basin.

Currently, coordinated data collection and information sharing in the Indus basin is being carried out under the aegis of the International Centre for Integrated Mountain Development's (ICIMOD) Upper Indus Basin Network (UIBN), see its Indus Knowledge Partnership Platform (https://www.icimod.org/initiative/indus-knowledge-partnership-platform/). The members of the UIBN are Afghanistan, China, India, Nepal and Pakistan. Member countries are expected (hence voluntary) to share new knowledge and information which will include information about new technology (ICIMOD, 2019). The International Water Management Institutes' Indus Basin Knowledge Forum helps to foster data sharing through its digital data and tools function but unless there is a legal framework providing for digital data and information exchange, these platforms are only as good as participating countries choose it to be. In the lower basin, the Centre for Water Informatics and Technology's Advisory Group Chair, Professor Wescoat, stated that WIT has devised data transmission technologies that 'monitor water flows precisely and in real time' (Saccoccia, 2016). However, this has obvious limitations as most of the challenges stem from the upper parts of the basin. This will only address the management issues within Pakistan's waters, which would not address the problems overall, especially the increasing environmental and human challenges.

4.3. Climate change and other environmental challenges

As well as the above challenges, climate change has exacerbated the challenges from damming to ecological flows due to its negative effects, especially in the downstream countries. This creates a considerable issue for data and information exchange among riparian states in any basin because environmental challenges in this century are more rapid and unprecedented. States need to exchange data regularly and more frequently to cope with these challenges. Lack of cooperation for data exchange will accelerate the scale and speed of environmental change to river basins. The lack of regular data exchange has already caused significant harm to lower parts of basins through damming and infrastructural development. It has also created a considerable gap in allocating

water in the basin. Climate change will only exacerbate the challenges to the basins through further projects as shown in the following examples.

The storage of water in projects built on river beds in the upper parts of the river basins within the upstream countries has caused a decrease in the flow of water in the streams and rivers in the lower parts of the basin within the downstream countries. According to Chomani & Bijnens (2016) and Al-Ansari *et al.* (2021), the upstream reservoirs have a negative impact on downstream countries. Based on the satellite images of the Sentinel-2, Table 1 shows that the level of water storage in the dams of the upstream countries has maintained almost the same level as it was in the previous year, while the level of water storage in the dams of the downstream countries has witnessed a remarkable decline. This means that the upstream countries have stored water at the expense of the water share of the downstream countries without any agreement.

Environmental changes are the reflection of the previous challenges on the ground, especially in the downstream countries. Al-Ansari *et al.* (2021) state that surface and subsurface water degradation, quantitatively and qualitatively, caused ecosystem damage and biodiversity loss across Iraq. The most prominent of these environmental changes are the retreat, drought and deterioration of the ecosystem of the marshes below the basin in southern Iraq, as recorded in satellite images.

In addition to environmental changes, environmental risks are forming another type of challenge that faces IWRM. Yousuf *et al.* (2018) consider the natural hazards caused by earthquakes, floods and droughts as the main tasks and responsibilities that must be taken into account. The great water storage projects in the upstream countries, which causes water shortage and scarcity in the downstream countries, can cause great flood hazards by dam failure due to earthquake activities because these projects are located near the subduction zones of Turkey and Iranian tectonic plates with the Arabian plate (Tosun *et al.*, 2007). Besides, Büyükakpınar *et al.* (2021) confirmed that seismic activity increased after filling the Ataturk Dam with water.

Pressures on the water resources and environmental challenges have also impacted the Indus basin, making it one of the world's most depleted and water-stressed basins (Laghari *et al.*, 2012 cited in Smolenaars *et al.*, 2022). The Indus Basin Irrigation System ('the IBIS'), the largest contiguous irrigation system in the world, constitutes an extensive system of diversion structures and canals on the Indus river basin with a total length of 56,000 km. The Indus Basin Project, which Pakistan implemented in the 1960s in order to replace the irrigation water supplies from tributaries allocated to India under the Indus Waters Treaty, consisted of the construction of two major

Table 1 | Difference in water storage in major dams in the Tigris-Euphrates basin

		Lake						Elevation (m)		
	Dams	Landsat 8 Imagery	Area (km^2)	Landsat 8 Imagery	Area (km^2)	Difference (km^2)	%	2019–2020	2020–2021	Difference
1	Ataturk	16-07-2020	772.37	19-07-2021	738.36	34.01	4.40333	537	533	– 4
2	Tishrin	16-07-2020	132.873	19-07-2021	113.031	19.842	14.93306	325	321	– 4
3	Tabaq	16-07-2020	611.853	19-07-2021	553.643	58.21	9.513723	304	299	– 5
4	Ilisu	18-07-2020	271.02	21-07-2021	178.77	92.25	34.03808	524	516	– 8
5	Musil	11-07-2020	298.9	16-07-2021	284.281	14.619	4.890933	325	319	– 6
6	Sardasht	13-07-2020	13.07	16-07-2021	12.52	0.55	4.20811	1017	1017	0
7	Dukan	20-07-2020	212.054	44384	171.18	40.874	19.27528	498	487	– 11
8	Dariyan	13-07-2020	4.471	16-07-2021	2.85	1.621	36.25587	828	826	– 2
9	Darbandikhan	13-07-2020	61.951	16-07-2021	36.124	25.827	41.6894	473	457	– 16

dams in Pakistan: the Mangla Dam and the Tarbela Dam (largest on the Indus River Basin). It formed part of a wider set of infrastructure projects to develop the IBIS further and facilitate the transfer of stored water from the Western Rivers to replace water lost from the Eastern Rivers. Table 2 lists the major reservoirs and hydroelectric projects in the Indus river basin.

The combined effects of the existing storage and diversion projects on the rivers have already had serious impacts on the Indus Delta in Pakistan. According to a study by the International Union for Conservation of Nature, the flow in the lower Indus river decreased from 105,000 MCM in 1932 to 43,000 MCM in 1970 as a result of the number of projects on the Indus and its tributaries. In the 1990s, the flow further reduced to 12,000 MCM (Water and Nature Initiative IUCN, 2003) and continues to decrease (Karrar, 2021). Sustained minimum river flow has led to a sharp reduction in the area of mangrove forests (the fifth largest mangrove system in the world), declining fish production, degraded water quality and severe encroachment of the sea into the delta area (the largest in the world) with a resultant loss of 4,856 km^2 of farmland (Water and Nature Initiative IUCN, 2003).

Due to the 22 upstream dams, Indus flows seldom cover 25% of its historic floodplain today. Over-extraction of groundwater in Pakistan is also adding pressure to the basin's water resources (World Bank, 2021). Additional dams will only aggravate such problems in the deltaic regions, affecting the hydrology of the basin as a whole. Climate change is already taking a toll in the basin, as evidenced by Pakistan's flash floods. In turn, these also affect food security as droughts and floods devastate agricultural production (World Bank, 2013). Hence, it is vital to address these challenges through the use of technologies, which is currently available.

5. OPPORTUNITIES

Considering the above challenges, the co-existence and co-management scenario is an optimal solution for sharing data between riparian states. This scenario presents an opportunity to ensure each country's historical, legal and geographic rights to water proportion based on data sharing and exchanging. The best available technology

Table 2 | Major dams in the Indus basin

Dam	Country	River	Year	Storage capacity (MCM)	Power (MW)
Baglihar	India	Chenab	2009	475	450
Bhakra	India	Satluj	1963	9,868	1,325
Bunji	Pakistan	Indus	Under construction	247	(7,100)
Chemera I	India	Ravi	1994	413	540
Diamer Bhasha	Pakistan	Indus	Under construction	9,991	(4,500)
Ghazi Barotha	Pakistan	Indus	2004	–	1,450
Mangla	Pakistan	Jhelum	1967	10,805	1,000
Nathpa-Jhakri	India	Satluj	2008	343	1,500
Pakal Dul	India	Chenab	Under construction	0.1254	(1,000)
Parbati II	India	Indus	Under construction	6.55	(800)
Pong	India	Beas	1974	8,570	396
Ranjit Sagar	India	Ravi	1999	3,280	600
Salal	India	Chenab	1986	28.5	690
Tarbela	Pakistan	Indus	1977	9,855.6	3,478

should be utilized to share data and information. Better technology will help generate a clearer picture of the present as well as prepare for the future. This, in turn, will drive more positive changes in law and policy.

5.1. Legal and institutional reform

Updating and reforming basin initiatives and agreements is the first and crucial point for future cooperation. In the Tigris and Euphrates river basins, the establishment of JTC was a significant step among the riparian states despite all obstacles and shortcomings. The re-establishment or reform of the JTC will be the first step for future cooperation and data exchange in the basin. However, the riparian states should invite Iran to join the JTC as one of the riparian states and an active actor in the basin. Then, the countries can create an independent basin institution for future long-term cooperation and data exchange (Gerlak *et al*., 2011).

While the Indus Waters Treaty has survived the geopolitics of the region to date, it needs an update as it has not been revised since its inception in 1960. The Treaty was drafted when, for example, climate change was not much of an issue and the scientific knowledge and technology were underdeveloped. While its provisions provide for regular data exchange, the use of the best available technology to collect data and share reliable information should ideally happen at the basin-wide level. This would require going beyond the Treaty between India and Pakistan and working with Afghanistan and China as well, given that a lot of the environmental issues, such as climate change and reduced environmental flows the basin is facing, cannot be dealt with effectively in isolation by individual states.

As the downstream countries are more vulnerable and will likely continue to face environmental disasters in the future, the upstream countries must be more cooperative in establishing joint committees and basin institutions with the downstream counties. The downstream countries do not have much to lose in presenting all initiatives and sharing data with upstream counties. This would be an initial step towards establishing trust and long-term cooperation. This step presents strong motivation and goodwill from downstream countries towards upstream countries. Vietnam could be considered a good example of a downstream country with its sharing and exchanging data with upstream countries and motivating them to cooperate on the Mekong river (Thu & Wehn, 2016).

5.2. Technical solutions

Co-management of river basins based on agreement among riparians and via a basin institution facilitates data and information on a higher level. As discussed in the previous sections, the basin institutions will be a reliable channel for sharing data on all aspects of IWRM. Basin institutions can share data via electronic and technological platforms that all the basins' upstream and downstream countries can use to share and exchange spatial data related to basin water management. Basin institutions using the IWRM can overcome the issues related to data quality, represented by the resolution (spatial, spectral, radiometric and temporal) and the accuracy of the spatial data (Dodge & Congalton, 2013). The higher the resolution and the accuracy of the information, the more reliable, valuable and dependable the information will be in IWRM and with higher negotiation power. The high-resolution data also produces effective ground and surface features of delineation outcomes (Anbazhagan *et al*., 2011).

Today, the ground surface is easily administered and regulated like a small village by the developed technology, platforms and software with the aid of space and air crafts. These advanced tools provide unlimited spatiotemporal data and information about land surface, environment, water resources, anthropogenic activities and behaviours, natural resources, etc. Data and information can be useful for various purposes, depending on their quality and resolution. In Iraq, many researchers (like Salar, 2013; Ali *et al*., 2016; Othman *et al*., 2021; Al-Attar *et al*., 2022; Salar *et al*., 2022) employed a large portion of these data for the land surface and watersheds

management. The more precise the data is, the more trustworthy the results will be. Quality data and information greatly assist in managing and monitoring transboundary water resources. They can be collected and stored on platforms associated with inter-state cooperative agencies involved in river basins, which include: (1) Online data and information such as Digital Elevation Model (DEM), satellite images, aerial photographs, SAR, LiDAR and climate data and (2) *in-situ* data such as hydrological gauging, recharge, discharge, seismic, geodetic, geoengineering, meteorological and irrigation system. Such data exchange properly facilitates transboundary river basin management and helps to overcome all the challenges faced by countries within the basin. Hence, the rights of each country can be fostered.

5.3. Social inclusion in data exchange

The social ecologies of cultures invigorate transboundary waters by reshaping the natural landscape, represented by water in recreating places, along with transitions towards peace, equity and cooperation. This requires collective interaction between political decision-makers in upstream and downstream countries, social movements and the grassroots of the environment to build a common future among people (Zawahri & Hensengerth, 2012). This creates opportunities to be highlighted and applied across all dimensions, including economic, agricultural, environmental and social, to achieve what is best for all, without benefits to one at the expense of the other.

As well as sharing data between riparian states, sharing data with the local people who live in the basin is fundamental for enhancing transparency and trust between states, and within states. This step increases awareness regarding water quality, scarcity and environmental changes among local people in the basin. The main issue in the above two cases is that upstream and downstream countries have not succeeded in building trust, accountability and transparency between the governments and communities in the basins. They failed to share data with local people in the basin. In the Tigris-Euphrates river basin, Kurdish people, the traditional owners of the upper part of the basin, with Arabs in the lower part of the basin, are dismissed in planning, management and decision-making (Hasan, 2023). In the Indus, data and information that is exchanged by the PIC are also not disclosed to members of the basin's community at all. This highlights another opportunity for institutional reform and use of technology.

6. CONCLUSION

Scarce data and information exchange is often symptomatic of a lack of comprehensive cooperation between riparian states. Data sharing and exchange is crucial to dealing with mounting human pressures on the limited water resources of river basins such as the Tigris and Euphrates and the Indus. Additional environmental challenges presented by issues like damming and climate change only exacerbate such problems. Customary international law reflected under the UN Convention provides for the exchange of data and information. It also provides a way to understand the various challenges that are impacting the basins and the type and level of solutions required to mitigate them, if not address them in their entirety. However, these two significant and complex case studies of the Indus and Tigris-Euphrates demonstrate that even if upstream countries reject principles of customary international law and do not engage in meaningful ways through established commissions, technological advancement can stimulate cooperation among riparians and offer opportunities to address the mounting anthropogenic and environmental problems such basins face.

It is not only difficult for riparian states to ignore established and emerging scientific facts provided by advances in technology and made available on non-political online platforms, particularly where this may indicate inequitable management of transboundary river basins, but it also taps into their sense of environmental responsibilities which is ultimately associated with the social and economic advancement of the peoples as well, now and in the future. This is even more urgent for the downstream countries such as Pakistan in the Indus and Iraq and Syrian

in the Tigris-Euphrates. Technological solutions which foster and enhance cooperation are relevant for all large transboundary basins that are highly politicized and face cooperation challenges. Furthermore, during negotiations and dispute resolution, riparian states can benefit from cross-basin studies which have adopted technological advancements for better data sharing and information exchange to reach an agreement.

While there is a large volume of literature that concentrates on legal and political challenges associated with transboundary river cooperation, we argue that data sharing and information exchange challenges are no less important. In fact, they are a crucial and an obvious part of the solution which cannot be ignored. The advancement of technology and the existing legal frameworks in these basins provide a platform for high ground surface data resolution and thus allow more credible and efficient information exchange to take place. These legal frameworks are not perfect, but greater cooperation and participation through quality data and information exchange between and within riparian states would mean that IWRM could be meaningfully implemented as is the intention behind this concept. If the human and environmental challenges are to be tackled, the optimum use of best available technology is most critical.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Al-Ansari, N., Saleh, S., Abdullah, T. & Abed, S. A. (2021). Quality of surface water and groundwater in Iraq. *Earth Sciences and Geotechnical Engineering 11*(2), 161–199.

Al-Attar, Z. T., Othman, A. A., Al-Hakari, S. H. S., Obaid, A. K., Salar, S. G. & Liesenberg, V. (2022). A neotectonic statistical assessment through watershed geomorphic analysis: a case study in the Greater Zab River Basin, Turkey–Iraq. *Environmental Earth Sciences 81*(13), 1–26.

Ali, S., Al-Umary, F. A., Salar, S. G., Al-Ansari, N. & Knutsson, S. (2016). GIS based soil erosion estimation using EPM method, Garmiyan Area, Kurdistan Region, Iraq. *Journal of Civil Engineering and Architecture 10*, 291–308.

Anbazhagan, S., Subramanian, S. K. & Yang, X. (2011). *Geoinformatics in Applied Geomorphology*. CRC Press, New York.

Atef, S. S., Sadeqinazhad, F., Farjaad, F. & Amatya, D. M. (2019). Water conflict management and cooperation between Afghanistan and Pakistan. *Journal of Hydrology 570*, 875–892.

Bagis, A. I. (1997). Turkey's hydropolitics of the Euphrates-Tigris Basin. *International Journal of Water Resources Development 13*(4), 567–582.

Berlin Rules on Water Resources. 2004. International Law Association.

Brachet, C. & Valensuela, D. (2012). *The Handbook for Integrated Water Resources Management in Transboundary Basins of Rivers, Lakes and Aquifers*. INBO-GWP, Paris.

Büyükakpınar, P., Cesca, S., Hainzl, S., Jamalreyhani, M., Heimann, S. & Dahm, T. (2021). Reservoir-triggered earthquakes around the Atatürk Dam (Southeastern Turkey). *Frontiers in Earth Science 9*, 353.

Cassese, A. (2005). *International Law*, 2nd edn. Oxford University Press, New York.

Chang, K. -T. (2019). *Introduction to Geographic Information Systems*, 9th edn. McGraw-Hill, Boston.

Chen, H., Rieu-Clarke, A. & Wouters, P. (2013). Exploring China's transboundary water treaty practice through the prism of the UN Watercourses Convention. *Water International 38*(2), 217–230.

Chomani, K. & Bijnens, T. (2016). The impact of the Daryan Dam on the Kurdistan Region of Iraq. In: *Save the Tigris and Iraqi Marches Campaign*., Walker, K. (ed.) https://www.hlrn.org/img/documents/Daryan-Dam-Report.pdf.

Convention on the Law of the Non-Navigational Uses of International Watercourses. 1997. United Nations Treaty Collection.

Convention on the Protection and Use of Transboundary Watercourses and International Lakes. 1992. United Nations Treaty Collection.

Devlaeminck, D. J. & Huang, X. (2020). China and the global water conventions in light of recent developments: Time to take a second look? *Review of European, Comparative & International Environmental Law 29*(3), 395–405.

Dodge, R. L. & Congalton, R. G. (2013). *Meeting Environmental Challenges with Remote Sensing Imagery*.

Faraj, D. M. & Zaidan, K. (2020). The impact of the tropical water project on Darbandikhan Dam and Diyala River Basin. *Iraqi Journal of Civil Engineering 14*(1), 1–6.

Fisheries Case (United Kingdom v Norway) [1951] ICJ 116.

Ganoulis, J., Aureli, A. & Fried, J. (2013). *Transboundary Water Resources Management: A Multidisciplinary Approach*. John Wiley & Sons, Weinheim.

GAP-RDA, S. A. P.-R. D. A. (2021). *History of GAP*. Available from: http://www.gap.gov.tr/en/history-page-3.html

Gerlak, A. K., Lautze, J. & Giordano, M. (2011). Water resources data and information exchange in transboundary water treaties. *International Environmental Agreements: Politics, Law and Economics 11*(2), 179–199.

GWP, INBO (2009). *A Handbook for Integrated Water Resources Management in Basins*. Global Water Partnership and International Network of Basin Organizations, Elanders.

Hasan, Q. M. (2023). *A trans-national analysis of equitable utilisation and minimisation of environmental harm under environmental laws at international, federal and national levels* (Doctoral dissertation, The University of Waikato).

Hasan, A., Pilesjö, P. & Persson, A. (2019). Setup a pilot hype model for the Tigris and Euphrates river basin to quantify the main factors causing water shortage in Iraq. In *Agu Fall Meeting Abstracts*. H14b-05.

Hassaniyan, A. & Sohrabi, M. (2022). Colonial management of Iranian Kurdistan; with emphasis on water resources. *Journal of World-Systems Research 28*, 320–343.

Hensengerth, O., Dombrowsky, I. & Scheumann, W. (2012). *Benefit-Sharing in Dam Projects on Shared Rivers*, Discussion Paper.

ICIMOD (2019). *Governance Framework: Upper Indus Basin-Network (UIB-N)*. ICIMOD, Kathmandu.

ICJ (2010). Pulp Mills on the River Uruguay (Argentina v Uruguay), Judgment, ICJ Reports 2010, 14.

Indus Waters Kishenganga Arbitration (Pakistan v India), Partial Award of 2013.

International Law Association (1967). The Helsinki rules on the uses of waters of international rivers 1966. In: *Helsinki Rules on the Uses of the Waters of International Rivers*. International Law Association, Geneva, pp. 7–55.

International Law Commission. (1994). Draft articles on the law of the non-navigational uses of international watercourses. *Yearbook of the International Law Commission 2*(2), 89–135.

Jacobs, I. M. & Nienaber, S. (2011). Waters without borders: transboundary water governance and the role of the transdisciplinary individual in Southern Africa. *Water SA 37*(5), 665–678.

Johns, C. & VanNijnatten, D. (2021). Using indicators to assess transboundary water governance in the Great Lakes and Rio Grande-Bravo Regions. *Environmental and Sustainability Indicators 10*, 100102.

Karrar, H. H. (2021). The Indus delta between past and future: precarious livelihoods and neoliberal imaginaries in a Parched Coastal Belt. *Journal of Indian Ocean World Studies 5*(1), 47–67.

Khan, R. S. (2022) 'Climate Scientists Explain Pakistan's "Unprecedented" Floods' *China Dialogue*. Available from: https://chinadialogue.net/en/climate/climate-scientists-explain-pakistan-floods-2022/.

Kibaroğlu, A. (2002). *Building a Regime for the Waters of the Euphrates-Tigris River Basin (Vol. 7)*. Martinus Nijhoff Publishers, Leiden.

Kibaroglu, A. (2019). State-of-the-art review of transboundary water governance in the Euphrates–Tigris River Basin. *International Journal of Water Resources Development 35*, 4–29.

Kibaroglu, A. & Ünver, I. O. (2000). An institutional framework for facilitating cooperation in the Euphrates-Tigris River Basin. *International Negotiation 5*(2), 311–330.

Kibaroglu, A., Klaphake, A., Kramer, A., Scheumann, W. & Carius, A. (2005). Cooperation on Turkey's Transboundary Waters. *Status Report Commissioned by the German Federal Ministry for Environment Nature Conservation and Nuclear Safety*, *F+E. Project* 903: 19.

Kliot, N. (1996). Hydropolitics and geopolitics in the Tigris-Euphrates River Basin. In: *Conference 'Water in the Middle East – A Source of Conflict or Cooperation'*.

Koeppel, S. (2008). Challenges and prospects of transboundary water management in Eastern Europe, Caucasus and Central Asia. In *Rescue of Sturgeon Species in the Ural River Basin*. Lagutov, V., (ed.) Springer, Dordrecht, pp. 29–38.

Kornfeld, I. (2020). *Mega-Dams and Indigenous Human Rights*. Edward Elgar Publishing, Northampton, MA.

Laghari, A. N., Vanham, D. & Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. *Hydrology and Earth System Sciences 16*, 1063–1083.

Liang, S. & Wang, J. (2019). *Advanced Remote Sensing: Terrestrial Information Extraction and Applications*. Academic Press, Oxford.

Mallapaty, S. (2022). Why are Pakistan's floods so extreme this year?. *Nature News*. Available from: https://www.nature.com/articles/d41586-022-02813-6

McCaffrey, S. (1986). *Second Report on the Law of the Non-Navigational Uses of International Watercourses*. United Nations.

McCaffrey, S. (2001). The contribution of the UN convention on the law of the non-navigational uses of international watercourses. *International Journal of Global Environmental Issues 1*(3–4), 250–263.

McCaffrey, S. C. (2008). The 1997 UN watercourses convention: retrospect and prospect. *Pacific McGeorge Global Business & Development Law Journal 21*, 165.

McCaffrey, S. C., (2019). Intertwined general principles. In *Research Handbook on International Water Law*. McCaffrey, S. C., Leb, C. & Denoon, R. T. (eds.). Edward Elgar, Cheltenham.

McIntyre, O. (2007). *Environmental Protection of International Watercourses Under International Law*. Ashgate, Hampshire.

Morvaridi, B. (2004). Resettlement, rights to development and the Ilisu Dam, Turkey. *Development and Change 35*, 719–741.

Orme, M., Cuthbert, Z., Sindico, F., Gibson, J. & Bostic, R. (2015). Good transboundary water governance in the 2015 sustainable development goals: a legal perspective. *Water International 40*(7), 969–983.

Othman, A. A., Obaid, A. K., Al-Manmi, D. A. M., Pirouei, M., Salar, S. G., Liesenberg, V., Al-Maamar, A. F., Shihab, A. T., Al-Saady, Y. I. & Al-Attar, Z. T. (2021). Insights for landfill site selection using GIS: a case study in the Tanjero River Basin, Kurdistan Region, Iraq. *Sustainability 13*(22), 12602.

Petersen, N., (2017). The role of consent and uncertainty in the formation of customary international law. In *Reexamining Customary International Law*. Lepard, B. D., (ed.). Cambridge University Press, pp. 111–130. https://doi-org.ezproxy.waikato.ac.nz/10.1017/9781316544624

Prost, G. L. (2014). *Remote Sensing for Geoscientists*, 3rd edn. CRC Press, New York.

Raman, D. (2014). Review of the Indus waters Kishenganga Arbitration (Final award) 2013: an ecological perspective. *Indian Journal of Arbitration Law 3*(2), 43–60.

Raman, D. (2015). *Governance of International Rivers: Threats, Gaps and Challenges*. *PhD Thesis*, Research Commons, University of Waikato.

Rieu-Clarke, A., (2013). International freshwater law. In *The Routledge Handbook of International Environmental Law*. Alam, S., Bhuiyan, M. J. H., Chowdhury, T. M. & Techera, E. J., (eds). Routledge, New York, p. 243.

Saccoccia, S. (2016) A smart water grid for the Indus Basin. *MIT Energy Initiative – News*. Available from: https://energy.mit.edu/news/smart-water-grid-indus-basin/

Salar, S. G. (2013). *Geomorphic Analysis for Water Harvesting Using GIS Technique in Selected Basins/Garmiyan Iraqi Kurdistan Region*. *PhD Thesis*, College of Science, University of Sulaimani.

Salar, S. G., Othman, A. A. & Hasan, S. E. (2018). Identification of suitable sites for groundwater recharge in Awaspi Watershed using GIS and remote sensing techniques. *Environmental Earth Sciences 77*(19), 1–15.

Salar, S. G., Othman, A. A., Rasooli, S., Ali, S. S., Al-Attar, Z. T. & Liesenberg, V. (2022). GIS-based Modeling for vegetated land fire prediction in Qaradagh Area, Kurdistan Region, Iraq. *Sustainability 14*(10), 6194.

Salewicz, K. A., Sakamoto, M. & Nakayama, M. (2021). Management of water resources using storage reservoirs. In *Tigris And Euphrates Rivers: Their Environment from Headwaters to Mouth*. Springer, Cham.

Salman, S. M. (2015). Entry into force of the UN watercourses convention: why should it matter? *International Journal of Water Resources Development 31*(1), 4.

Sands, P., Peel, J., Fabra, A. & MacKenzie, R. (2012). *Principles of International Environmental Law*, 3rd edn. Cambridge University Press, Cambridge.

Smolenaars, W. J., Dhaubanjar, S., Jamil, M. K., Lutz, A., Immerzeel, W., Ludwig, F. & Biemans, H. (2022). Future upstream water consumption and its impact on downstream water availability in the transboundary Indus basin. *Hydrology and Earth System Sciences 26*, 861–883.

Syria, I. A. (1990). *Law No. 14 of 1990, Ratifying the Joint Minutes Concerning the Provisional Division of the Waters of the Euphrates River*. https://www.informea.org/en/legislation/law-no-14-1990-ratifying-joint-minutes-concerning-provisional-division-waters-euphrates.

Thu, H. N. & Wehn, U. (2016). Data sharing in international transboundary contexts: the Vietnamese perspective on data sharing in the Lower Mekong Basin. *Journal of Hydrology 536*, 351–364.

Tosun, H., Zorluer, İ., Orhan, A., Seyrek, E., Savaş, H. & Türköz, M. (2007). Seismic hazard and total risk analyses for large dams in Euphrates basin, Turkey. *Engineering Geology 89*(1–2), 155–170.

Turkey, S. A. R. A. (1987). *Protocol on Matters Pertaining to Economic Cooperation*. Available from: https://www.un-ilibrary.org/content/books/9789210596435s002-c001/read

UN-ESCWA, B. (2013). United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe. *Inventory of Shared Water Resources in Western Asia, Beirut*.

United Nations (1997). *General Assembly Official Records, 51st Sess.: 99th Plenary Meeting, Wednesday, 21 May 1997, New York*. United Nations Digital Library. Available from: https://digitallibrary.un.org/record/234835?ln=en

United Nations. (2022). *Convention on the Law of the Non-Navigational Uses of International Watercourses*.

Water and Nature Initiative IUCN (The World Conservation Union) (2003). *The Lower Indus River: Balancing Development and Maintenance of Wetland Ecosystems and Dependent Livelihoods* Microsoft Word – CaseStudy-Indus.doc (indianstrategicknowledgeonline.com)

World Bank (2013). *Indus Basin of Pakistan: Impacts of Climate Risks on Water and Agriculture*. Available from: https://openknowledge.worldbank.org/handle/10986/13834

World Bank (2021). *Report: Groundwater in Pakistan's Indus Basin: Present and Future Prospects*. Available from: https://openknowledge.worldbank.org/handle/10986/35065

Yadirgi, V. (2020). Turkey's Kurdish question in the era of neoliberalism. *Journal of Balkan and Near Eastern Studies 22*, 793–809.

Yousuf, M. A., Rapantova, N. & Younis, J. H. (2018). Sustainable water management in Iraq (Kurdistan) as a challenge for governmental responsibility. *Water 10*(11), 1651.

Yuksel, I. (2015). South-eastern Anatolia Project (GAP) factor and energy management in Turkey. *Energy Reports 1*, 151–155.

Zawahri, N. A. & Hensengerth, O. (2012). Domestic environmental activists and the governance of the Ganges and Mekong Rivers in India and China. *International Environmental Agreements: Politics, Law and Economics 12*(3), 269–298.

First received 4 December 2022; accepted in revised form 7 July 2023. Available online 18 July 2023